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Preliminary Composite Channel Model for the Mobile User Objective System Including Ionospheric Scintillation and Terrestrial Multipath Effects

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PRELIMINARY COMPOSITE CHANNEL MODEL FOR THE MOBILE USER OBJECTIVE SYSTEM INCLUDING IONOSPHERIC SCINTILLATION AND TERRESTRIAL MULTIPATH EFFECTS

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ABSTRACT

A composite channel model, which combines ionospheric scintillation fading and terrestrial multipath effects, has been developed for the new satellite communications system, the Mobile User Objective System (MUOS). We numerically solve the composite model and compute an effective decorrelation time and coherence bandwidth for the composite channel. We find that, under typical conditions, the effective channel decorrelation time and coherence bandwidth can be different from the ionospheric or terrestrial channel parameters.

INTRODUCTION

The Mobile User Objective System (MUOS) will provide satellite communications for a wide range of operational environments and for a large class of user terminals. The typical MUOS operational environments can be classified as land, ocean,

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and aeronautical-mobile satellite communications channels. Each of these channels has propagation conditions ranging from benign to stressed. For example, due to ionospheric effects, MUOS signal transmissions can suffer both amplitude and phase scintillation and associated fading at both low and high latitudes depending on geomagnetic conditions. Strong ionospheric scintillation can also occur at UHF during magnetic storms at mid latitudes over the continental United States. In addition, in terrestrial environments, e.g., urban, suburban, maritime, strong multipath can also lead to signal fading. In the past ionospheric scintillation and terrestrial multipath fading have been studied separately. Some initial efforts have been made to develop a composite model [1-5]. A composite model is important for waveform design, signal demodulation, and fading mitigation. However a quantitative composite model has not been developed to date. In this preliminary study we develop a coupled model for the combined effects of ionospheric scintillation and terrestrial multipath. We then numerically solve the model for channel parameters for an urban multipath environment undergoing ionospheric scintillation.

MODEL

For the Rician ionospheric scintillation channel we take the following expression for the signal auto-correlation function [1]

$$\begin{aligned} R_1(\tau,\Delta f) &= S_0[p + q\rho(\tau,\Delta f)]\exp(i2\pi\delta f\tau) && \text{Rician} \\ &= S_0\rho(\tau,\Delta f)\exp(i2\pi\delta f\tau) && \text{Rayleigh} \end{aligned} \tag{1}$$

where $S_0 = R_1(\tau=0,\Delta f=0)$ is the total signal power, $pS_0 = S_s$ is the specular power and $qS_0 = S_r$ is the random or Rayleigh power, $\rho(\tau,\Delta f)$ is the normalized ionospheric scintillation auto-correlation function for the Rayleigh portion, and δf is the Doppler frequency shift for a moving mobile platform. If $p = 0$ ($q = 1$) $S_s = 0$ and $S_r = S_0$ and we have Rayleigh fading. The general expression for the signal auto-correlation function [1,3]

$$R(\tau,\Delta f) = \langle E(t+\tau,f+\Delta f)E^*(t,f)\rangle \tag{2}$$

where E is the complex envelope representation of the signal with * denoting complex conjugate and <.> the expectation operator. For the Rayleigh scintillation channel

without terminal Doppler we have the normalized auto-correlation function [1,2]

$$\rho(\tau,\Delta f) = R(\tau,\Delta f)/R(0,0) \qquad R(0,0) = R(\tau{=}0,\Delta f{=}0) \qquad (3)$$
$$= \exp[-(\tau/\tau_{01})^2/(1+i\Delta f/f_{01}]/(1+i\Delta f/f_{01}] \qquad \text{Rayleigh}$$

where τ_{01} is the signal decorrelation time and f_{01} is the channel coherence bandwidth. This specific result has been derived in [1,6]. Given this normalized auto-correlation function the channel signal decorrelation time τ_0 and coherence bandwidth f_0 are defined by the relationships $\rho''_\tau(0,0) = -2/\tau_0^2$ and $\rho''_{\Delta f}(0,0) = -2/f_0^2$ where $\rho''_\tau(0,0) = R''_\tau(0,0)/R(0,0)$ and $\rho''_{\Delta f}(0,0) = R''_{\Delta f}(0,0)/R(0,0)$ denote the second derivatives of $\rho(\tau,\Delta f)$ and $R(\tau,\Delta f)$ with respect to τ and Δf, respectively, evaluated at $\tau = 0$ and $\Delta f = 0$. For the Rayleigh scintillation channel with $R(\tau,\Delta f) = S_0\rho(\tau,\Delta f)$, we obtain the channel signal decorrelation time and coherence bandwidth

$$\tau_0 = \mathrm{sqrt}[2R(0,0)/|R''_\tau(0,0)|] = \tau_{01} \qquad \text{Decorrelation Time} \qquad (4a)$$
$$f_0 = \mathrm{sqrt}[2R(0,0)/|R''_{\Delta f}(0,0)|] = f_{01} \qquad \text{Coherence Bandwidth} \qquad (4b)$$

as one would expect. [Note that the second derivatives are always non-positive.]

The decorrelation time and coherence bandwidth of Rician ionospheric channel (1) can also be determined from the general expressions

$$\tau_0 = \mathrm{sqrt}[2R_1(0,0)/|R''_{1\tau}(0,0)|] = \tau_{01}/\mathrm{sqrt}[q+2\tau_{01}^2(\pi\delta f)^2] \qquad (5a)$$
$$f_0 = \mathrm{sqrt}[2R_1(0,0)/|R''_{1\Delta f}(0,0)|] = f_{01}/\mathrm{sqrt}(q) \qquad (5b)$$

We see that as the specular component becomes more significant ($q = 1-p$ becomes smaller) be both the decorrelation time and coherence bandwidth becomes larger.

For the terrestrial multipath channel we have the following expression for the signal auto-correlation function [1]

$$R_2(\tau,\Delta f) = S_0[\exp(i2\pi\delta f\tau) + m\rho_2(\tau,\Delta f)] \qquad (6)$$

where S_0 is the specular signal power and mS_0 is the multipath (random) power for the total signal power $(1+m)S_0 = R_2(\tau{=}0,\Delta f{=}0)$. The normalized terrestrial multipath auto-

correlation function $\rho_2(\tau,\Delta f)$ is taken to be [1]

$$\rho_2(\tau,\Delta f) = \exp(-i2\pi\Delta f\tau)[J_0(a)J_0(b)+2\Sigma_{n=1}^{\infty}(-1)^n J_n(a)J_n(b)\cos\{n(\alpha_0-\alpha_s)\}] \tag{7}$$

where $a = 2\pi(v_0/\lambda)\tau\cos(\beta_0)$, $b = 2\pi(\Delta f/f_c)(r_m/\lambda)\cos(\beta_s)$ that the angles define the unit direction vector $u(\alpha_s,\beta_s)=[\cos(\alpha_s)\cos(\beta_s), \sin(\alpha_s)\cos(\beta_s), \sin(\beta_s)]$ towards the satellite as seen from the terminal and $u(\alpha_0,\beta_0)=[\cos(\alpha_0)\cos(\beta_0), \sin(\alpha_0)\cos(\beta_0), \sin(\beta_0)]$ is the terminal multipath length, λ is the UHF wavelength, f_c is the UHF signal frequency, J_n is the Bessel function of the first kind of order n. The decorrelation time and coherence bandwidth corresponding to the auto-correlation function become

$$\tau_{02} = \mathrm{sqrt}[2/|\rho''_{2\tau}(0,0)|] = \lambda/[\pi v_0\cos(\beta_0)] \tag{8a}$$
$$f_{02} = \mathrm{sqrt}[2/|\rho''_{2\Delta f}(0,0)|] = (c/\pi r_m)/\mathrm{sqrt}[2+\cos^2(\beta_s)] \tag{8b}$$

where $c = f_c\lambda$ being the speed of light (300 m/μs). The decorrelation time and channel coherence bandwidth associated with the terrestrial channel

$$\tau_0 = \mathrm{sqrt}[2R_2(0,0)/|R''_{2\tau}(0,0)|] = \tau_{02}\mathrm{sqrt}[(1+m)/\{m+2\tau_{02}^2(\pi\delta f)^2] \tag{9a}$$
$$f_0 = \mathrm{sqrt}[2R_2(0,0)/|R''_{2\Delta f}(0,0)|] = f_{02}\mathrm{sqrt}(1+1/m) \tag{9b}$$

since in this case $R_2(0,0) = (1+m)S_0$.

The composite scintillation and terrestrial channel signal auto-correlation function can now be expressed as

$$R_3(\tau,\Delta f) = S_0[p + q\rho(\tau,\Delta f)][\exp(i2\pi\delta f\tau) + m\rho_2(\tau,\Delta f)] \tag{10}$$

where again the total power $(1+m)S_0 = R_3(\tau=0,\Delta f=0)$ where specular power component is pS_0 and the random power component is $(1+m-p)S_0$. The channel signal decorrelation time and channel coherence bandwidth can be solved from

$$\tau_0 = \mathrm{sqrt}[2R_2(0,0)/|R''_{2\tau}(0,0)|] = \mathrm{sqrt}[(1+m)/\{q/\tau_{01}^2+m/\tau_{02}^2+2(\pi\delta f)^2\}] \tag{11a}$$
$$f_0 = \mathrm{sqrt}[2R_2(0,0)/|R''_{2\Delta f}(0,0)|] = \mathrm{sqrt}[(1+m)/\{q/f_{01}^2+m/f_{02}^2\}] \tag{11b}$$

We see that when $m = 0$ (no terrestrial multipath) we have the same result as (5a,b) and when the multipath is dominating as expected $\tau_0 = \tau_{02}$ and $f_0 = f_{02}$ as $m \Rightarrow \infty$.

RESULTS

We solve Eq. (10) numerically using a carrier frequency of $f_c = 250$ MHz. For the ionospheric scintillation channel we take a decorrelation time of $\tau_0 = 0.6$ sec and a coherence bandwidth of $f_o = 1$ MHz. For the terrestrial channel we take $v_0 = 30$ mph, or 48.3 Km/hr, and $r_m/\lambda = 100$. Fig. 1 gives the normalized composite signal auto-correlation function as a function of time offset τ for $\Delta f = 0$. We find, that for these channel parameters, the effective composite channel decorrelation time is larger than the ionospheric channel decorrelation time.

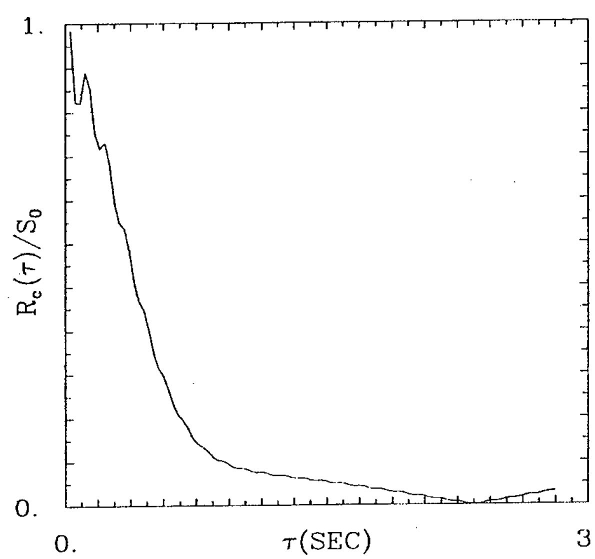

Fig. 1 Plot of normalized composite correlation function vs. τ for Δf=0.

Fig. 2 shows the normalized composite signal auto-correlation function as a function of frequency offset Δf for τ=0. We also find that the effective composite channel coherence bandwidth is larger than the ionospheric scintillation coherence bandwidth.

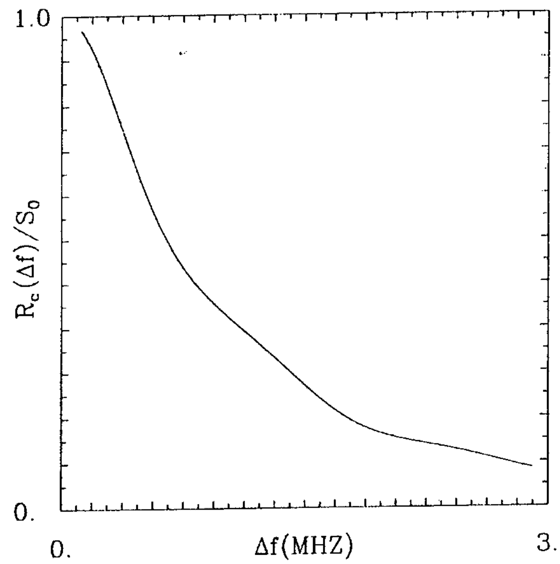

Fig. 2 Plot of normalized composite correlation function as a function of Δf for τ=0.

SUMMARY

We have developed a preliminary composite model for the combined effects of ionospheric scintillation and terrestrial multipath on a MUOS signal waveform. The composite model gives an effective decorrelation time and coherence bandwidth for the composite channel. We have found that the effective decorrelation time and coherence bandwidth of the composite channel can be different from the ionospheric channel parameters. In the future we will solve the composite model for a larger range of channel parameters.

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